

08/11/00  
JC849 U.S. PTO

08-14-00

**ADAMS & WILKS**  
ATTORNEYS AND COUNSELORS AT LAW  
50 BROADWAY  
31st FLOOR  
NEW YORK, NEW YORK 10004

JC813 U.S. PTO  
09/638194  
08/11/00

BRUCE L. ADAMS  
VAN C. WILKS\*

JOHN R. BENEFIEL\*  
PAUL R. HOFFMAN  
TAKESHI NISHIDA  
FRANCO S. DE LIGUORI\*

\* NOT ADMITTED IN NEW YORK  
\* REGISTERED PATENT AGENT

**BY EXPRESS MAIL ON**  
AUGUST 11, 2000  
(EJ 876 888 089 US)

RIGGS T. STEWART  
(1924-1993)

TELEPHONE  
(212) 809-3700

FACSIMILE  
(212) 809-3704

Box PATENT APPLICATION  
ASSISTANT COMMISSIONER FOR PATENTS  
Washington, DC 20231

RECORD OF TRANSMITTAL

INVENTOR(s): (1) Sumio KOIWA

TITLE: PHOTODIODE

DOCKET NO: S004-4061

S I R:

Kindly find enclosed herewith for filing the documents checked below. Any fees or charges not covered by the accompanying check should be charged to our Deposit Account No. 01-0268.

APPLICABLE ITEMS CHECKED:

- XX PATENT APPLICATION (pages 1-10 of specification, 3 claim(s) (page(s) 9, abstract and declaration and power of attorney)
- DESIGN APPLICATION (specification, claim, declaration and power of attorney and photograph(s))
- XX FORMAL DRAWINGS (1 sheets) (NI A4)
- INFORMAL DRAWINGS (       sheets)
- RECORDATION FORM COVER SHEET and ASSIGNMENT  
(to be recorded and returned to the undersigned)

XX PRIORITY CLAIM - applicant(s) claim the benefit of priority  
of the following application(s):

Japanese Patent Appln. No. 11-295840  
filed Oct. 18, 1999

XX PRIORITY DOCUMENT(s)

       Enclosed XX Not Enclosed

       VERIFIED STATEMENT TO ESTABLISH SMALL ENTITY STATUS

XX EXPRESS MAIL CERTIFICATION

       OTHER -

XX FEE

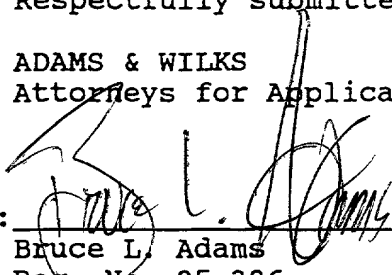
A check is enclosed for the following official fees:

	Large Entity	Small Entity
<u>XX</u> Basic Filing Fee	\$ 690.00	\$
<u>0</u> Independent Claims in Excess of 3	\$	\$
<u>0</u> Total Claims in Excess of 20	\$	\$
<u>      </u> Multiple Claim Fee	\$	\$
<u>      </u> Assignment Recordal Fee	\$	\$
TOTAL	\$ 690.00	\$

Respectfully submitted,

ADAMS & WILKS  
Attorneys for Applicant(s)

50 Broadway  
31st Floor  
New York, NY 10004  
(212) 809-3700

By:   
Bruce L. Adams  
Reg. No. 25,386

JC813 U.S. PTO  
09/638194  
08/11/00

Re: New patent application of Sumio KOIWA et al.  
for PHOTODIODE

comprising transmittal letter, title, specification (pgs. 1-9), 3 claims (pg.9), abstract of the disclosure, (pg.10), one sheet of formal drawings containing thereon Figs. 1-3, express mail certification and check in the amount \$690.00

Attorney's Docket No: S004-4061

**EXPRESS MAIL CERTIFICATION UNDER 37 CFR §1.10**

Express Mail Tracking Number: EJ 876 888 089 US

Date of Deposit: **AUGUST 11, 2000**

I hereby certify that this paper or fee is being deposited with the United States Postal Service "Express Mail Post Office to Addressee" service under 37 CFR §1.10 on the date indicated above and is addressed to Box PATENT APPLICATION, ASSISTANT COMMISSIONER OF PATENTS, Washington, DC 20231.



Michael Ruas

# PHOTODIODE

## BACKGROUND OF THE INVENTION

### 1. Field of the Invention

The present invention relates to a photodiode, and particularly to a structure for improving the short wavelength region photo sensitivity of a photodiode.

### 2. Description of the Related Art

Conventionally, a photodiode is used as an optical detection element, for example, as a signal detection element of an optical pickup. In recent years, because of an increase in capacity of an optical disk, there has been proposed optical disk readout by a short wavelength semiconductor laser with blue light or violet light. Thus, the short wavelength region photo sensitivity of the photodiode becomes very important.

Fig. 2 is a sectional view of a conventional photodiode.

In Fig. 2, the photodiode is constituted by a first conductive type semiconductor region 1, for example, an N-type silicon semiconductor substrate, and a second conductive type semiconductor layer 2 formed on the surface of the first conductive type semiconductor region 1, for example, a P-type diffusion layer. An antireflection film 5, for example, an oxide film is formed on the photodiode. A reverse bias is applied to the first conductive type semiconductor region 1 and the second conductive type semiconductor

layer 2, and when light is irradiated to a depletion layer 3 formed by the reverse bias application, an optical signal is generated in the depletion layer 3.

The depth of the second conductive type semiconductor layer 2 of the photodiode in Fig. 2 is optimized in accordance with a wavelength to be detected, and for example, in the case where red light of a wavelength of about 800 nm is detected, the depth of the second conductive type semiconductor layer 2 is made about 3  $\mu\text{m}$ . In the case where blue or violet light of a wavelength of about 400 nm is detected, light of a wavelength of about 400 nm is easily absorbed by silicon and is almost absorbed in a depth of about 1  $\mu\text{m}$ . Thus, in order to detect short wavelength light of a wavelength of about 400 nm in a conventional photodiode, it is necessary that the depth of the second conductive type semiconductor layer 2 is made 1  $\mu\text{m}$  or less. However, in the conventional photodiode, since it is difficult to control the depth of the second conductive type semiconductor layer 2 so that the depth becomes 1  $\mu\text{m}$  or less, there has been a problem that light sensitivity in a short wavelength region is inferior.

If a plurality of second conductive type semiconductor layers 2 are formed as in a photodiode shown in Fig. 3, a depletion layer 3 is formed on the surface of a first conductive type semiconductor region between the second conductive type semiconductor layers 2a and 2b, so that the photo sensitivity in a short wavelength region

is improved. However, an interface level 4 is formed on the surface of the first conductive type semiconductor region between the second conductive type semiconductor layers 2a and 2b, and an optical signal generated in the depletion layer 3 between the second conductive type semiconductor layers 2a and 2b is trapped by the interface level 4, so that there has been a problem that the photo sensitivity is lowered and leak current is increased.

#### SUMMARY OF THE INVENTION

The present invention has been made in view of the above circumstances, and has an object to provide a photodiode which can improve the photo sensitivity in a shorter wavelength region as compared with a conventional photodiode without increasing leak current.

In order to solve the above-mentioned problem, according to the present invention, a photodiode includes a first conductive type semiconductor region, and a plurality of second conductive type semiconductor layers formed on the surface of the first conductive type semiconductor region, the first conductive type semiconductor region and the plurality of second conductive type semiconductor layers constituting an optical detection portion for detecting an optical signal and outputting its photoelectric conversion signal, wherein the surface of the first conductive type semiconductor region between the second conductive type

semiconductor layers is removed. Like this, since the surface of the first conductive type semiconductor region between the second conductive type semiconductor layers is removed, the interface level of the surface of the first conductive type semiconductor region between the second conductive type semiconductor layers is removed.

Besides, the surface of the first conductive type semiconductor region is removed by a wet etching method, so that the region can be removed without generating an interface level due to etching damage.

In the photodiode of the present invention, the plurality of second conductive type semiconductor layers are formed on the surface of the first conductive type semiconductor region.

When a reverse bias is applied to the photodiode constituted by the first conductive type semiconductor region and the second conductive type semiconductor layers, a depletion layer is extended in accordance with the bias voltage. Since the depletion layer is extended not only in the vertical direction but also in the horizontal direction, the depletion layer is also formed on the surface of the first conductive type semiconductor region, and the photo sensitivity in a short wavelength region is improved. At this time, since the respective second conductive type semiconductor layers are made to have the same potential. Thus, when the distance between the second conductive type semiconductor layers is made

about twice the width of the depletion layer, since the depletion layers of adjacent photodiodes formed of the first conductive type semiconductor region and the second conductive type semiconductor layers just come in contact with each other, the efficiency is excellent.

Further, in the first conductive type semiconductor region between the second conductive type semiconductor layers, the interface level is formed on the surface of the first conductive type semiconductor region, and by removing the interface level, the leak current can be controlled without greatly influencing the photo sensitivity of the photodiode.

Besides, when the interface level of the surface of the first conductive type semiconductor region is removed by using the wet etching method, the interface level can be removed without generating an interface level due to etching damage.

#### BRIEF DESCRIPTION OF THE DRAWINGS

In the accompanying drawings:

Fig. 1 is a schematic sectional view showing a photodiode of the present invention;

Fig. 2 is a second schematic sectional view showing a conventional photodiode; and

Fig. 3 is a first schematic sectional view showing a conventional photodiode.



#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

An embodiment of the present invention will be described below with reference to the drawings. Fig. 1 a schematic sectional view showing an embodiment of a photodiode of the present invention.

In Fig. 1, a plurality of second conductive type semiconductor layers 2a and 2b, for example, P-type impurity diffusion layers are formed on the surface of a first conductive type semiconductor region 1, for example, an N-type silicon semiconductor substrate. The first conductive type semiconductor region 1 and the second conductive type semiconductor layers 2a and 2b are reversely biased so that a depletion layer 3 is formed. The plurality of second conductive type semiconductor layers 2a and 2b are electrically connected to each other, and the second conductive type semiconductor layers 2a and 2b have the same potential.

The interface level of the surface of the first conductive type semiconductor region 1 between the second conductive type semiconductor layers 2a and 2b is removed by a wet etching method, for example, wet etching using a silicon etching solution of KOH, EPW (ethylene diamine pyrocatechol & water), TMAH (tetramethylammonium hydroxide),  $\text{HF} + \text{HNO}_3$ , or the like. It is needless to say that the removal of the interface level of the surface of the first conductive type region 1 has only to be carried out at least at a portion between the second conductive type

semiconductor layers 2a and 2b.

It is needless to say that the respective conductive types may be reversed. For example, a plurality of first conductive type semiconductor layers are formed on a second conductive type semiconductor region, and the interface level of the surface of the second conductive type semiconductor region between the first conductive type semiconductor layers is removed by a wet etching method.

Further, it is needless to say that a portion between the second conductive type semiconductor layers is not limited to only one portion, but plural portions may be formed.

As described above, the photodiode of the present invention has effects as set forth below.

The plurality of second conductive type semiconductor layers are formed on the surface of the first conductive type semiconductor region, and a reverse bias is applied to the first conductive type semiconductor region and the second conductive type semiconductor layers, so that the depletion layer is formed on the surface of the first conductive type semiconductor region between the second conductive type semiconductor layers, and the photo sensitivity in a short wavelength region is improved.

Further, when the distance between the second conductive type semiconductor layers is made 0.5 to 2 times the width of the depletion layer in the horizontal direction formed by the reverse

bias, since the depletion layers of adjacent photodiodes formed of the first conductive type semiconductor region and the second conductive type semiconductor layers come in contact with each other, it becomes possible to detect an optical signal with excellent area efficiency.

Besides, since the interface level of the surface of the first conductive type semiconductor region between the second conductive type semiconductor layers is removed, the leak current can be suppressed without greatly influencing the photo sensitivity.

Besides, since the interface level of the surface of the first conductive type semiconductor region between the second conductive type semiconductor layers is removed by using the wet etching method, the interface level can be removed without generating an interface level due to etching damage.

WHAT IS CLAIMED IS:

1. A photodiode comprising a first conductive type semiconductor region, and a plurality of second conductive type semiconductor layers formed on a surface of the first conductive type semiconductor region, the first conductive type semiconductor region and the plurality of second conductive type semiconductor layers constituting an optical detection portion for detecting an optical signal and outputting its photoelectric conversion signal, wherein

the surface of the first conductive type semiconductor region between the second conductive type semiconductor layers is removed.

2. A photodiode according to claim 1, wherein a distance between the second conductive type semiconductor layers formed on the surface of the first conductive type semiconductor region is 0.5 to 2 times a width of a depletion layer in a horizontal direction formed by reverse bias application.

3. A photodiode according to claim 1, wherein the surface of the first conductive type semiconductor region between the second conductive type semiconductor layers is removed by a wet etching method.

ABSTRACT OF THE DISCLOSURE

There is provided a photodiode which can improve photo sensitivity in a short wavelength region without increasing leak current. A plurality of second conductive type semiconductor layers are formed on the surface of a first conductive type semiconductor region, and the surface of the first conductive type semiconductor region between the second conductive type semiconductor layers is removed.

OFFICE OF THE ATTORNEY GENERAL

FIG. 1

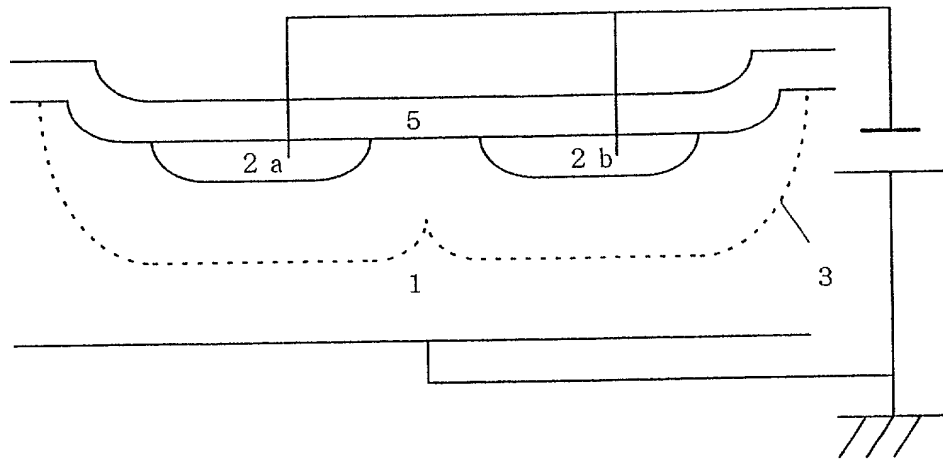


FIG. 2 PRIOR ART

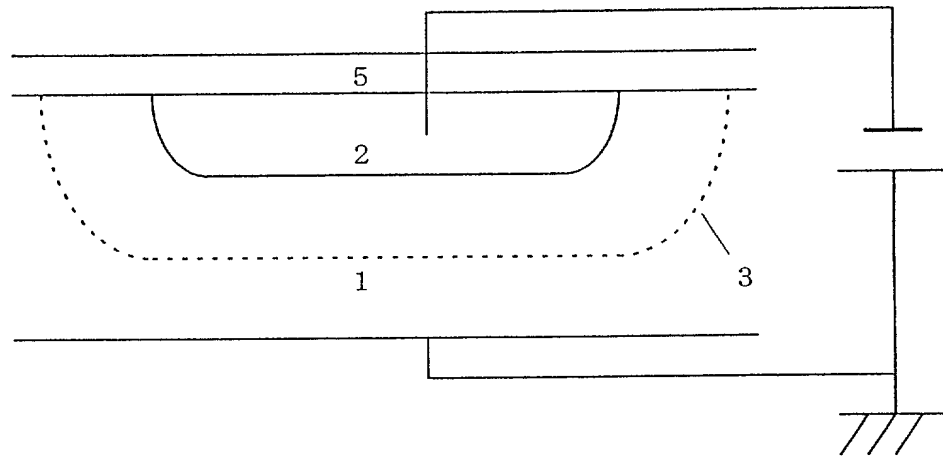


FIG. 3 PRIOR ART

